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# Nonequilibrium Mechanics of Active Cytoskeletal Networks : from in vitro model system to cultured living cells(Poster session 2, New Frontiers in Colloidal Physics : A Bridge between Micro- and Macroscopic Concepts in Soft Matter)

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# Nonequilibrium Mechanics of Active Cytoskeletal Networks

## — from in vitro model system to cultured living cells —

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細胞は、力学的なフレームワークである細胞骨格システムを介して動的に力を発生し、また、内外から加えられた力に対して敏感に反応している。この生きた細胞骨格システムは、生体高分子やモーター蛋白質からなる非平衡な複合体である。今回われわれは、ミオシンII、アクチンフィラメント、クロスリンカーの三要素から成る単純なin vitroモデルを作成し、その動態と力学的性質を測定した。このモデル系では、モーター蛋白質の働きにより生じる内部応力によって細胞骨格ネットワークの力学物性が調節され、ネットワークの粘弾性応答はATP濃度に依存して約100倍変化した。われわれはこの非平衡ゲルのメゾスコピックスケールの力学特性と分子レベルの力発生機構とを関連付ける定量的理論モデルを提示する。さらにこの理論モデルが実際に生きている細胞骨格ネットワークにも適用可能であることを培養細胞を利用した実験により確認した。

Mechanics directly controls many functions of cells: motion, force generation, and mechanosensing. The cytoskeleton is a network of semiflexible filamentous proteins that is responsible for most of the mechanical functions of cells. One of the principal features of the cytoskeleton in vivo is its non-equilibrium character, due to mechanoenzymes (motor proteins). Prior in vitro studies, however, have focused on passive structures in equilibrium.

Here we show for the first time how non-equilibrium motor activity controls the mechanical properties of in vitro model of the cytoskeleton [1]. We applied both active and passive microrheology techniques [3] to a simple three-component system consisting of myosin II, actin filaments, and crosslinkers. The non-equilibrium origin of this active mechanical control was demonstrated by the violation of a fundamental principle/theorem of equilibrium statistical physics: the fluctuation-dissipation theorem. We show that nonequilibrium stresses arising from motor activity exquisitely controls cytoskeletal network mechanics: both increasing stiffness by nearly 100 times and qualitatively changing the viscoleastic response of the network in an ATP-dependent manner. We present a quantitative theoretical model connecting the large-scale

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properties of this active gel to molecular force generation.

We also present studies on intracellular mechanics of cultured fibroblasts, which show that our physical description of in vitro active cytoskeleton is applicable to in vivo cytoskeletons [2].

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